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PART II

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MECHANICAL DRAWING

PART II

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MECHANICAL DRAWING

PART II

In Part I the instructions and the problems worked out have been designed to teach the student the elementary operations of Mechanical Drawing, giving him a knowledge of the instruments, an ability to draw a straight and true line, and to make up simple figures. A fair degree of drawing ability is now assumed and we can pass on to more complicated problems. Wherever we turn for subjects, however, we find a knowledge of geometrical figures and their properties is absolutely essential to a clear understanding of the problems chosen and we will therefore turn to a discussion of these geometrical figures and the problems which involve them.

GEOMETRICAL DEFINITIONS

A *point* is used for marking position; it has neither length, breadth, nor thickness.

LINES

A *line* has length only; it is produced by the motion of a point.

A *straight line* or *right line* is one that has the same direction throughout. It is the shortest distance between two points.

A *curved line* is one that is constantly changing in direction. It is sometimes called a curve.

A *broken line* is one made up of several straight lines.

Parallel lines are lines which lie in the same plane and are equally distant from each other at all points.

A *horizontal line* is one having the direction of a line drawn upon the surface of water that is at rest. It is a line parallel to the horizon.

A *vertical line* is one that lies in the direction of a thread suspended from its upper end and having a weight at the lower end. It is a line that is perpendicular to a horizontal plane.

An *oblique line* is one that is neither vertical nor horizontal.

In Mechanical Drawing, lines drawn along the edge of the T-square, when the head of the T-square is resting against the left-hand edge of the board, are called *horizontal* lines. Those drawn at right angles or perpendicular to the edge of the T-square are called *vertical* lines.

If two lines cut each other, they are called *intersecting lines*, and the point at which they cross is called the *point of intersection*.

ANGLES

An *angle* is the measure of the difference in direction of two lines. The lines are called *sides*, and the point of meeting, the

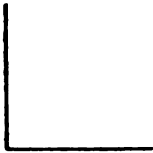


Fig. 40. Right Angle

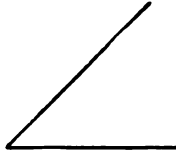


Fig. 41. Acute Angle

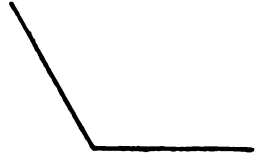


Fig. 42. Obtuse Angle

vertex. The size of an angle is independent of the length of the lines.

If one straight line meets another (extended if necessary), Fig. 40, so that the two angles thus formed are equal, the lines are said to be *perpendicular* to each other and the angles formed are called *right angles*.

An *acute angle* is less than a right angle, Fig. 41.

An *obtuse angle* is greater than a right angle, Fig. 42.

SURFACES

A *surface* is produced by the motion of a line; it has two dimensions—length and breadth.

A *plane figure* is a plane bounded on all sides by lines; the space included within these lines (if they are straight lines) is called a *polygon* or a *rectilinear figure*.

POLYGONS

A *polygon* is a plane figure bounded by straight lines. The boundary lines are called the *sides* and the sum of the sides is called the *perimeter*.

Polygons are classified according to the number of sides.

A *triangle* is a polygon of *three* sides.

A *quadrilateral* is a polygon of *four* sides.

A *pentagon* is a polygon of *five* sides, Fig. 43.

A *hexagon* is a polygon of *six* sides, Fig. 44.

A *heptagon* is a polygon of *seven* sides.

An *octagon* is a polygon of *eight* sides, Fig. 45.

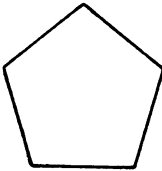


Fig. 43. Pentagon

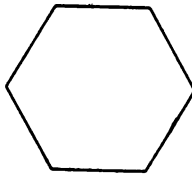


Fig. 44. Hexagon

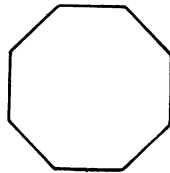


Fig. 45. Octagon

A *decagon* is a polygon of *ten* sides.

A *dodecagon* is a polygon of *twelve* sides.

An *equilateral* polygon is one all of whose sides are equal.

An *equiangular* polygon is one all of whose angles are equal.

A *regular* polygon is one all of whose angles and all of whose sides are equal.

Triangles. A triangle is a polygon enclosed by three straight lines called *sides*. The *angles* of a triangle are the angles formed by the sides.

A *right-angled* triangle, often called a *right* triangle, Fig. 46, is one that has a right angle. The longest side (the one opposite

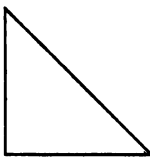


Fig. 46. Right-Angled Triangle

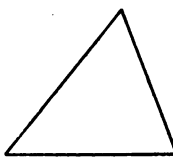


Fig. 47. Acute Angled Triangle

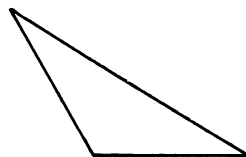


Fig. 48. Obtuse-Angled Triangle

the right angle) is called the *hypotenuse*, and the other sides are sometimes called *legs*.

An *acute-angled* triangle is one that has all of its angles acute, Fig. 47.

An *obtuse-angled* triangle is one that has an obtuse angle, Fig. 48.

An *equilateral* triangle is one having all of its sides equal, Fig. 49.

An *equiangular* triangle is one having all of its angles equal.

An *isosceles* triangle, Fig. 50, is one, two of whose sides are equal.
 A *scalene* triangle, Fig. 51, is one, no two of whose sides are equal.

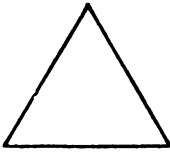


Fig. 49. Equilateral Triangle

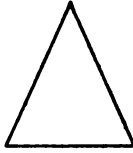


Fig. 50. Isosceles Triangle

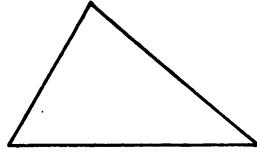


Fig. 51. Scalene Triangle

The *base* of a triangle is the lowest side; it is the side upon which the triangle is supposed to stand. Any side may, however, be taken as the base. In an isosceles triangle, the side which is not one of the equal sides is usually considered as the base.

The *altitude* of a triangle is the perpendicular drawn from the vertex to the base.

Quadrilaterals. A quadrilateral is a polygon bounded by four straight lines, as Fig. 52.

The *diagonal* of a quadrilateral is a straight line joining two opposite vertices.

Trapezium. A trapezium is a quadrilateral, no two of whose sides are parallel.

Trapezoid. A trapezoid is a quadrilateral having two sides



Fig. 52. Quadrilateral

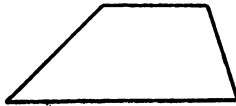


Fig. 53. Trapezoid



Fig. 54. Parallelogram

parallel, Fig. 53. The parallel sides are called the *bases* and the perpendicular distance between the bases is called the *altitude*.

Parallelogram. A parallelogram is a quadrilateral whose opposite sides are parallel, Fig. 54.

There are four kinds of parallelograms: rectangle, square, rhombus, and rhomboid.

The *rectangle*, Fig. 55, is a parallelogram whose angles are right angles.

The *square*, Fig. 56, is a parallelogram all of whose sides are equal and whose angles are right angles.

The *rhombus*, Fig. 57, is a parallelogram whose sides are equal but whose angles are not right angles.



Fig. 55. Rectangle

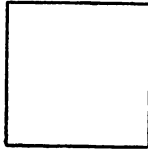


Fig. 56. Square

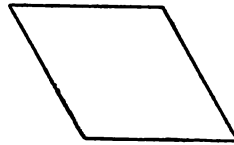


Fig. 57. Rhombus

The *rhomboid* is a parallelogram whose adjacent sides are unequal, and whose angles are not right angles.

CIRCLES

A *circle* is a plane figure bounded by a curved line called the *circumference*, every point of which is equally distant from a point within called the *center*, Fig. 58.

A *diameter* of a circle is a straight line drawn through the center, terminating at both ends in the circumference, Fig. 59.

A *radius* of a circle is a straight line joining the center with the

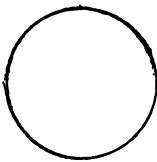


Fig. 58. Circle

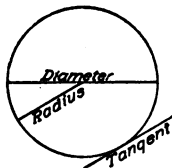
Fig. 59. Diameter,
Radius, Tangent

Fig. 60. Quadrant

circumference. All radii of the same circle are equal and their length is always one-half that of the diameter.

An *arc* is any part of the circumference of a circle. An arc equal to one-half the circumference is called a *semi-circumference*, and an arc equal to one-quarter of the circumference is called a *quadrant*, Fig. 60. A quadrant may mean the arc or angle.

A *chord*, Fig. 61, is a straight line which joins the extremities of an arc but does not pass through the center of the circle.

A *secant* is a straight line which intersects the circumference in two points, Fig. 61.

A *segment* of a circle, Fig. 62, is the area included between an arc and a chord.

A *sector* is the area included between an arc and two radii drawn to the extremities of the arc, Fig. 62.

A *tangent* is a straight line which touches the circumference at only one point, called the *point of tangency or contact*, Fig. 59.

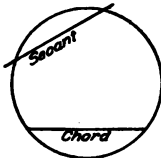


Fig. 61. Chord and Secant

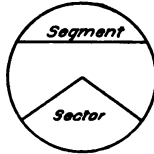


Fig. 62. Segment and Sector

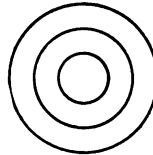


Fig. 63. Concentric Circles

Concentric circles are circles having the same center, Fig. 63.

An *inscribed angle* is an angle whose vertex lies in the circumference and whose sides are chords. It is measured by one-half the intercepted arc, Fig. 64.

A *central angle* is an angle whose vertex is at the center of the circle and whose sides are radii, Fig. 65.

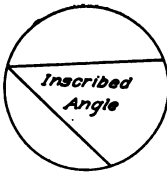


Fig. 64. Inscribed Angle

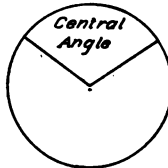


Fig. 65. Central Angle

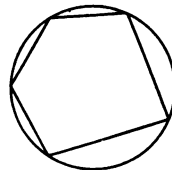


Fig. 66. Inscribed Polygon

An *inscribed polygon* is one whose vertices lie in the circumference and whose sides are chords, Fig. 66.

MEASUREMENT OF ANGLES

To measure an angle, take any convenient radius and describe an arc with the center at the vertex of the angle. The portion of the arc included between the sides of the angle is the *measure of the angle*. If the arc has a constant radius, the greater the divergence of the sides, the longer will be the arc. If there are several arcs drawn with the same center, the intercepted arcs will have different lengths but they will all be the *same fraction* of the entire circumference.

In order that the size of an angle or arc may be stated without saying that it is a certain fraction of a circumference, the circumference is divided into 360 equal parts called *degrees*, Fig. 67. Thus, it may be said that a certain angle contains 45 degrees, *i.e.*, it is $\frac{45}{360} = \frac{1}{8}$ of a circumference. In order to obtain accurate measurements each degree is divided into 60 equal parts called *minutes* and each minute into 60 equal parts called *seconds*.

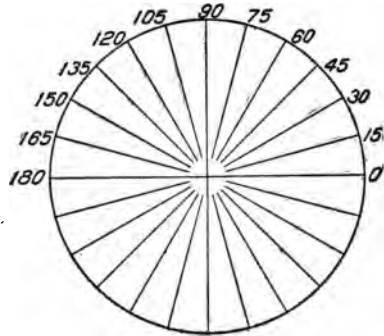


Fig. 67. Angular Measurement

SOLIDS

A *solid* has three dimensions—length, breadth, and thickness. The most common forms of solids are *polyhedrons*, *cylinders*, *cones*, and *spheres*.

POLYHEDRONS

A *polyhedron* is a solid bounded by planes. The bounding planes are called *faces* and their intersections are called *edges*. The intersections of the edges are called *vertices*.

A polyhedron having four faces is called a *tetrahedron*; one having six faces, a *hexahedron*; one having eight faces, and *octahedron*, Fig. 68; one having twelve faces, a *dodecahedron*, etc.

Prisms. A prism is a polyhedron having two opposite faces, called *bases*, which are equal and parallel, and other faces, called

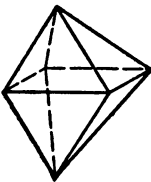


Fig. 68. Octahedron

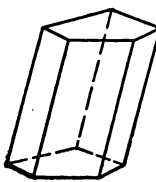


Fig. 69. Prism

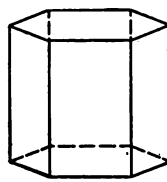


Fig. 70. Right Prism

lateral faces, which are parallelograms, Fig. 69. The *altitude* of a prism is the perpendicular distance between the bases. The area of the lateral faces is called the *lateral area*.

Prisms are called *triangular*, *rectangular*, *hexagonal*, etc., according to the shape of the bases. Further classifications are as follows:

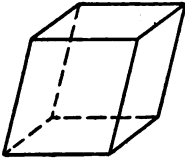


Fig. 71. Parallelopiped

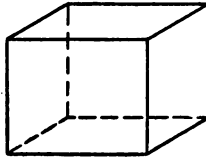


Fig. 72. Rectangular Parallelopiped

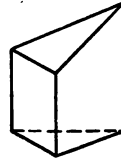


Fig. 73. Truncated Prism

A *right prism* is one whose lateral faces are perpendicular to the bases, Fig. 70.

A *regular prism* is a right prism having regular polygons for bases.

Parallelopiped. A parallelopiped is a prism whose bases are parallelograms, Fig. 71. If all the edges are perpendicular to the bases, it is called a *right parallelopiped*.

A *rectangular parallelopiped* is a right parallelopiped whose bases and lateral faces are rectangles, Fig. 72.

A *cube* is a rectangular parallelopiped all of whose faces are squares.

A *truncated prism* is the portion of a prism included between the base and a plane not parallel to the base, Fig. 73.

Pyramids. A pyramid is a polyhedron whose base is a polygon and whose lateral faces are triangles having a common vertex called the *vertex* of the pyramid.

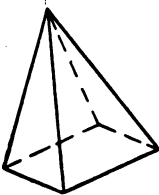


Fig. 74. Pyramid

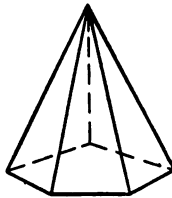


Fig. 75. Regular Pyramid

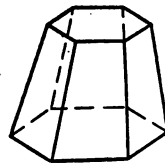


Fig. 76. Frustum of Pyramid

The *altitude* of the pyramid is the perpendicular distance from the vertex to the base.

Pyramids are named according to the kind of polygon forming the base, viz, *triangular*, *quadriangular*, Fig. 74. *pentagonal*, Fig. 75, *hexagonal*.

A *regular pyramid* is one whose base is a regular polygon and whose vertex lies in a perpendicular erected at the center of the base, Fig. 75.

A *truncated pyramid* is the portion of a pyramid included between the base and a plane not parallel to the base.

A *frustum* of a pyramid is the solid included between the base and a plane parallel to the base, Fig. 76; its *altitude* is the perpendicular distance between the bases.

CYLINDERS

A *cylinder* is a solid having as bases two equal parallel surfaces bounded by curved lines, and as its lateral face the continuous

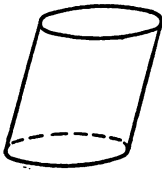


Fig. 77. Cylinder

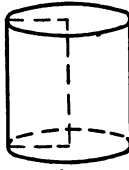


Fig. 78. Right Cylinder

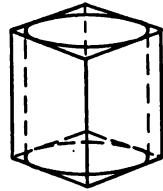


Fig. 79. Inscribed Cylinder

surface generated by a straight line connecting the bases and moving along their circumferences. The bases are usually circles and such a cylinder is called a *circular cylinder*, Fig. 77.

A *right cylinder*, Fig. 78, is one whose side is perpendicular to the bases.

The *altitude* of a cylinder is the perpendicular distance between the bases.

A prism whose base is a regular polygon may be inscribed in or circumscribed about a circular cylinder, Fig. 79.

CONES

A *cone* is a solid bounded by a conical surface and a plane which cuts the conical surface. It may be considered as a pyramid with an infinite number of sides, Fig. 80.

The conical surface is called the *lateral area* and it tapers to a point called the *vertex*; the plane is called the *base*.

The *altitude* of a cone is the perpendicular distance from the vertex to the base.

An *element* of a cone is any straight line from the vertex to the circumference of the base.

A *circular cone* is a cone whose base is a circle.

A *right circular cone*, or *cone of revolution*, Fig. 81, is a cone



Fig. 80. Cone

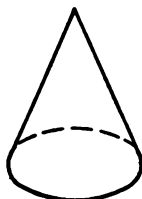


Fig. 81. Right Circular Cone

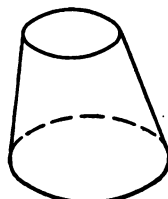


Fig. 82. Frustum of Cone

whose axis is perpendicular to the base. It may be generated by the revolution of a right triangle about one of the legs as an axis.

A *frustum* of a cone, Fig. 82, is the portion of the cone included between the base and a plane parallel to the base; its *altitude* is the perpendicular distance between the bases.

SPHERES

A *sphere* is a solid bounded by a curved surface, every point of which is equally distant from a point within called the *center*.

The *diameter* is a straight line drawn through the center and having its extremities in the curved surface. The *radius*— $\frac{1}{2}$ diameter—is the straight line from the center to a point on the surface.

A *plane is tangent to a sphere* when it touches the sphere in only

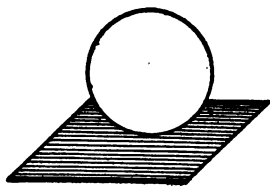


Fig. 83. Plane Tangent to Sphere

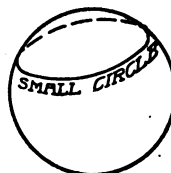


Fig. 84. Great and Small Circle

one point. A plane perpendicular to a radius at its outer extremity is tangent to the sphere, Fig. 83.

An *inscribed polyhedron* is a polyhedron whose vertices lie in the surface of the sphere.

A *circumscribed polyhedron* is a polyhedron whose faces are tangent to a sphere.

A *great circle* is the intersection of the spherical surface and a plane passing through the center of the sphere, Fig. 84.

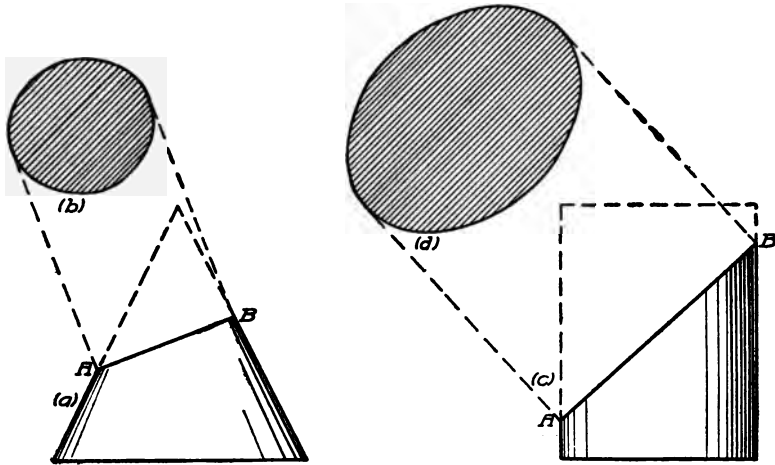


Fig. 85. Intersections of Plane with Cone and Cylinder Giving Ellipses as Shown in (b) and (d)

A *small circle* is the intersection of the spherical surface and a plane which does not pass through the center, Fig. 84.

CONIC SECTIONS

If a plane intersects a cone at various angles with the base the geometrical figures thus formed are called *conic sections*. A plane perpendicular to the base passing through the vertex of a right circular cone forms an isosceles triangle. If the plane is parallel to the base, the intersection of the plane and the conical surfaces will be the circumference of a circle.

Ellipse. If a plane AB , Fig. 85a, cuts a cone oblique to the axis of the cone, but not cutting the base, the curve formed is called an ellipse, as shown in Fig. 85b, this view being taken perpendicular to the plane AB . If the plane cuts a cylinder as shown in Fig. 85c, the ellipse shown in Fig. 85d is the result, this view being also taken perpendicular to the plane AB . An ellipse may be defined as a curve generated by a point

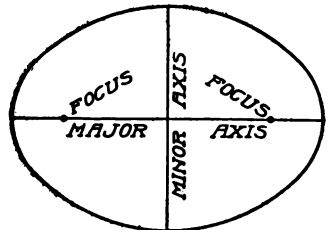


Fig. 86. Diagram Showing Constants of Ellipse

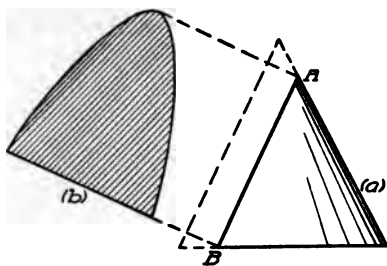


Fig. 87. Intersection of Plane with Cone, Parallel to Element of Cone and Parabolic Section Produced

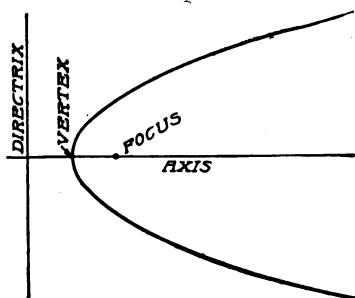


Fig. 88. Diagram Showing Constants of Parabola

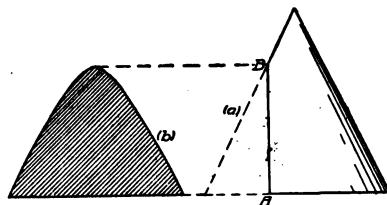


Fig. 89. Intersection of Plane with Cone, Parallel to Axis and Hyperbolic Section Produced

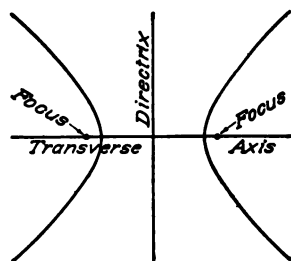


Fig. 90. Diagram Showing Constants of Hyperbola

moving in a plane in such a manner that the sum of the distances from the point to two fixed points shall always be constant.

The two fixed points are called *foci*, Fig. 86, and shall lie on the longest line that can be drawn in the ellipse which is called the *major axis*; the shortest line is called the *minor axis*; and is perpendicular to the major axis at its middle point, called the *center*.

An ellipse may be constructed if the major and minor axes are given or if the foci and one axis are known.

Parabola. If a plane AB , Fig. 87a, cuts a cone parallel to an element of the cone, the curve resulting from this intersection is called a parabola, as shown in Fig. 87b, the view being taken perpendicular to the plane AB . This curve is not a closed curve for the branches approach parallelism.

A parabola may be defined as a curve every point of which is equally distant from a line and a point.

The point is called the *focus*, Fig. 88, and the given line, the *directrix*. The line perpendicular to the directrix and passing through the focus is the *axis*. The intersection of the axis and the curve is the *vertex*.

Hyperbola. If a plane AB , Fig. 89a, cuts a cone parallel to its axis, the resulting curve is called a hyperbola,

Fig. 89b, the view being taken perpendicular to the plane AB .

Like the parabola, the curve is not closed, the branches constantly diverging.

A hyperbola is defined as *a plane curve such that the difference between the distances from any point in the curve to two fixed points is equal to a given distance.*

The two fixed points are the *foci* and the line passing through them is the *transverse axis*, Fig. 90.

Rectangular Hyperbola. The form of hyperbola most used in Mechanical Engineering is called the rectangular hyperbola because it is drawn with reference to rectangular coördinates. This curve is constructed as follows: In Fig. 91, OX and OY are the two coördinate axes drawn at right angles to each other. These lines are also called *asymptotes*. Assume A to be a known point on the curve. Draw AC parallel to OX and AD' perpendicular to OX . Mark off any convenient

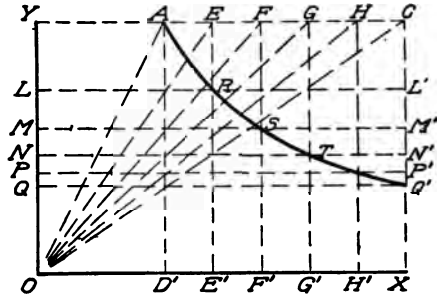


Fig. 91. Construction of Rectangular Hyperbola

points on AC such as E , F , G , and H , and through these points draw EE' , FF' , GG' , and HH' , perpendicular to OX . Connect E , F , G , H , and C with O . Through the points of intersection of the oblique lines and the vertical line AD' draw the horizontal lines LL' , MM' , NN' , PP' , and QQ' . The first point on the curve is the assumed point A , the second point is R , the intersection of LL' and EE' , the third the intersection S , and so on.

In this curve the products of the coördinates of all points are equal. Thus $LR \times RE' = MS \times SF' = NT \times TG'$.

ODONTOIDAL CURVES

Cycloidal Curves. *Cycloid.* The cycloid is a curve generated by a point on the circumference of a circle which rolls on a straight line tangent to the circle, as shown at the left, Fig. 92.

The rolling circle is called the *describing* or *generating circle*, the point on the circle, the *describing* or *generating point*, and the

tangent along which the circle rolls, the *director*. In order that the curve described by the point may be a true cycloid the circle must roll without any slipping.

Hypocycloid. In case the generating circle rolls upon the inside of an arc or circle, the curve thus generated is a hypocycloid,

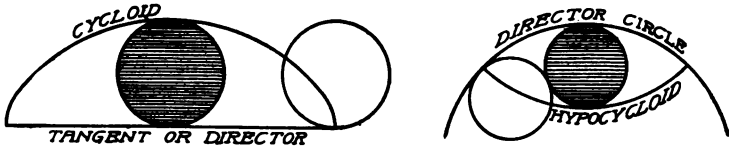


Fig. 92. Geometrical Constructions for Cycloid and Hypocycloid

Fig. 92. If the generating circle has a diameter equal to the radius of the director circle the hypocycloid becomes a straight line.

Epicycloid. If the generating circle rolls upon the *outside* of the *director circle*, the curve generated is an epicycloid, Fig. 93.

Involute Curves. If a thread of fine wire is wound around a cylinder or circle and then unwound, the end will describe an involute curve. The involute may be defined as *a curve generated by a point in a tangent rolling on a circle, known as the base circle*, Fig. 94.

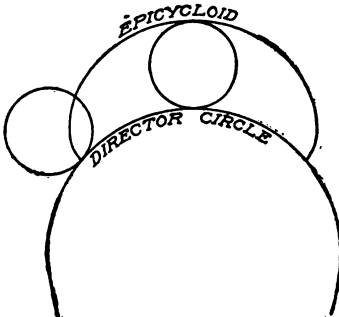


Fig. 93. Geometrical Construction for an Epicycloid

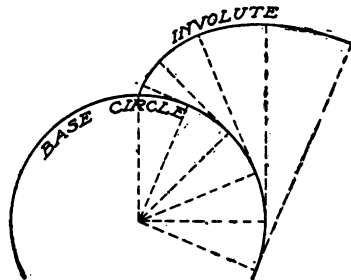


Fig. 94. Geometrical Construction for an Involute

The details of the ellipse, parabola, hyperbola, cycloid, and involute will be taken up in connection with the plates.

The most important application of the cycloidal and involute curves is in the cutting of all forms of gear teeth. It has been found that the teeth of gears when cut accurately to either of these curves will mesh with the least friction and run with exceptional smoothness. The development of these gears and of the machines for cutting them has reached a high state of perfection.

GEOMETRICAL PROBLEMS

The problems given in Plates IV to VIII inclusive have been chosen because of their particular bearing on the work of the mechanical draftsman. They should be solved with great care, as the principles involved will be used in later work.

PLATE IV

Penciling. The horizontal and vertical center lines and the border lines should be laid out in the same manner as in *Plate I*. Now measure off $2\frac{1}{4}$ inches on both sides of the vertical center line and through these points draw vertical lines as shown by the dot and dash lines, *Plate IV*. In locating the figures, place them a little above the center so that there will be room for the number of the problem.

Draw in lightly the lines of each figure with pencil and after the entire plate is completed, ink them. In penciling, all intersections must be formed with great care as the accuracy of the results depends upon it. Keep the pencil points in good order at all times and draw lines *exactly* through intersections.

Problem 1. *To bisect a given straight line.*

Draw the horizontal straight line AC about 3 inches long. With the extremity A as a center and any convenient radius—about 2 inches—describe arcs above and below the line AC . With the other extremity C as a center and with the same radius draw similar arcs intersecting the first arcs at D and E . The radius of these arcs must be greater than one-half the length of the line in order that they may intersect. Now draw the straight line DE passing through the intersections D and E . This line will cut AC at its middle point F .

Therefore

$$AF = FC$$

Proof. Since the points D and E are equally distant from A and C a straight line drawn through them is perpendicular to AC at its middle point F .

Problem 2. *To construct an angle equal to a given angle.*

Draw the line OC about 2 inches long and the line OA of about the same length. The angle formed by these lines may be

PLATE IV

Problem 1

Problem 2

Problem 3

Problem 4

Problem 5

Problem 6

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any convenient size—about 45 degrees is suitable. This angle AOC is the given angle.

Now draw FG , a horizontal line about $2\frac{1}{4}$ inches long, and let F , the left-hand extremity, be the vertex of the angle to be constructed.

With O as a center and any convenient radius—about $1\frac{1}{2}$ inches—describe the arc LM cutting both OA and OC . With F as a center and the same radius draw the indefinite arc OQ . Now set the compass so that the distance between the pencil and the needle point is equal to the chord LM . With Q as a center and a radius equal to LM draw an arc cutting the arc OQ at P . Through F and P draw the straight line FE . The angle EFG is the required angle since it is equal to AOC .

Proof. Since the chords of the arcs LM and PQ are equal, the arcs are equal. The angles are equal because with equal radii equal arcs are intercepted by equal angles.

Problems 3 and 4. *To draw through a given point a line parallel to a given line.*

First Method. Draw the straight line AC about $3\frac{1}{2}$ inches long and assume the point P about $1\frac{1}{2}$ inches above AC . Through the point P draw an oblique line FE forming any convenient angle—about 60 degrees—with AC . Now construct an angle equal to PEC having its vertex at P and the line EP as one side. (See Problem 2.) The straight line PO forming the other side of the angle EPO will be parallel to AC .

Proof. If two straight lines are cut by a third making the corresponding angles equal, the lines are parallel.

Second Method. Draw the straight line AC about $3\frac{1}{2}$ inches long and assume the point P about $1\frac{1}{2}$ inches above AC . With P as a center and any convenient radius—about $2\frac{1}{2}$ inches—draw the indefinite arc ED cutting the line AC . Now with the same radius and with D as a center, draw an arc PQ . Set the compass so that the distance between the needle point and the pencil is equal to the chord PQ . With D as a center and a radius equal to PQ , describe an arc cutting the arc ED at H . A line drawn through P and H will be parallel to AC .

Proof. Draw the line QH . Since the arcs PQ and HD are equal and have the same radii, the angles PHQ and HQD

are equal. Two lines are parallel if the alternate interior angles are equal.

Problems 5 and 6. *To draw a perpendicular to a line from a point in the line.*

First Method. WHEN THE POINT IS NEAR THE MIDDLE OF THE LINE.

Draw the line AC about $3\frac{1}{2}$ inches long and assume the point P near the middle of the line. With P as a center and any convenient radius—about $1\frac{1}{4}$ inches—draw two arcs cutting the line AC at E and F . Now with E and F as centers and any convenient radius—about $2\frac{1}{2}$ inches—describe arcs intersecting at O . The line OP will be perpendicular to AC at P .

Proof. The points P and O are both equally distant from E and F . Hence a line drawn through them is perpendicular to EF at P .

Second Method. WHEN THE POINT IS NEAR THE END OF THE LINE.

Draw the line AC about $3\frac{1}{2}$ inches long. Assume the given point P to be about $\frac{3}{4}$ inch from the end A . With any point D as a center and a radius equal to DP , describe an arc cutting AC at E . Through E and D draw the diameter EO . A line from O to P is perpendicular to AC at P .

Proof. The angle OPE is inscribed in a semicircle; hence it is a right angle, and the sides OP and PE are perpendicular to each other.

Lettering. After completing these figures draw pencil lines for the lettering. Place the words "*Plate IV*" and the date and the name in the border, as in preceding plates. To letter the words "Problem 1," "Problem 2," etc., draw three horizontal lines $\frac{1}{4}$ inch, $\frac{3}{8}$ inch, and $\frac{1}{8}$ inch, respectively, above the horizontal center line and the lower border line to serve as a guide for the size of the letters.

Inking. In inking *Plate IV*, ink in the figures first. Make the line AC , Problem 1, a full line as it is the given line; make the arcs and the line DE dotted as they are construction lines. Similarly in Problem 2, make the sides of the angles full lines and the chord LM and the arcs dotted. Follow the same plan in inking the lines of Problems 3, 4, 5, and 6. In Problem 6, ink in only that part of the circumference which passes through the points O , P , and E .

After inking the figures, ink in the heavy border line, and the lettering.

PLATE V

Pencilling. In laying out the border lines and center lines follow the directions given for *Plate IV*. Draw the dot and dash lines in the same manner, as there are to be six problems on this plate.

Problem 7. *To draw a perpendicular to a line from a point without the line.*

Draw the straight line AC about $3\frac{1}{4}$ inches long, and assume the point P about $1\frac{1}{2}$ inches above the line. With P as a center and any convenient radius—about 2 inches—describe an arc cutting AC at E and F . The radius of this arc must always be such that it will cut AC in two points; the nearer the points E and F are to A and C , the greater will be the accuracy of the work.

Now with E and F as centers and any convenient radius—about $2\frac{1}{4}$ inches—draw the arcs intersecting below AC at T . A line through the points P and T will be perpendicular to AC . In case there is not room below AC to draw the arcs, they may be drawn intersecting above the line as shown at N . Whenever convenient draw the arcs below AC for greater accuracy.

Proof. Since P and T are both equally distant from E and F , the line PT is perpendicular to AC .

Problems 8 and 9. *To bisect a given angle.*

First Method. WHEN THE SIDES INTERSECT.

Draw the lines OC and OA —about 3 inches long—forming any angle of 45 to 60 degrees. With O as a center and any convenient radius—about 2 inches—draw an arc intersecting the sides of the angle at E and F . With E and F as centers and a radius of $1\frac{1}{2}$ or $1\frac{3}{4}$ inches, describe short arcs intersecting at I . A line OD , drawn through the points O and I , bisects the angle.

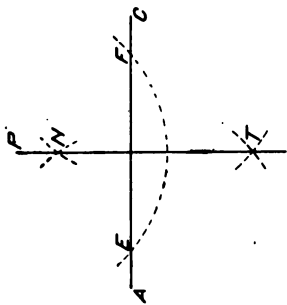
In solving this problem the arc EF should not be too near the vertex if accuracy is desired.

Proof. The central angles AOD and DOC are equal because the arc EF is bisected by the line OD . The point I is equally distant from E and F .

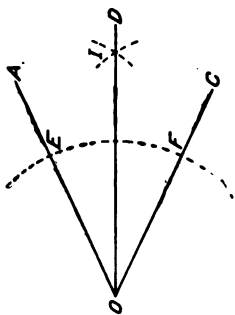
Second Method. WHEN THE LINES DO NOT INTERSECT.

Draw the lines AC and EF about 4 inches long making an

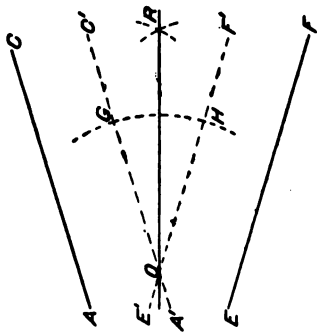
PLATE V



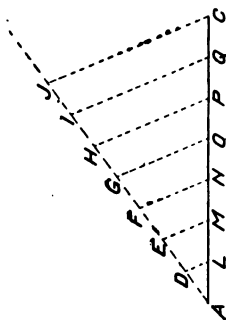
Problem 7



Problem 8



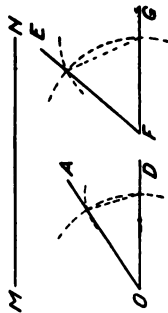
Problem 9



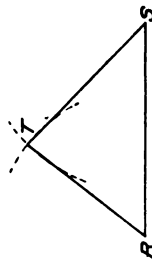
Problem 10



Problem 11



Problem 12



angle approximately as shown. Draw $A'C'$ and $E'F'$ parallel to AC and EF and at such equal distances from them that they will intersect at O . Now bisect the angle $C'OF'$ by the method given in Problem 8. The line OR bisects the given angle.

Proof. Since $A'C'$ is parallel to AC and $E'F'$ is parallel to EF , the angle $C'OF'$ is equal to the angle formed by the lines AC and EF . Hence as OR bisects angle $C'OF'$ it also bisects the angle formed by the lines AC and EF .

Problem 10. *To divide a line into any number of equal parts.*

Let AC —about $3\frac{3}{4}$ inches long—be a given line. Suppose it is desired to divide it into 7 equal parts. First draw the line AJ at least 4 inches long, forming any convenient angle with AC . On AJ lay off, by means of the dividers or scale, points D, E, F, G , etc., each $\frac{1}{2}$ inch apart. (If dividers are used, the spaces need not be exactly $\frac{1}{2}$ inch.) Draw the line JG and through the points D, E, F, G , etc., draw lines parallel to JG . These parallels will divide the line AC into 7 equal parts.

Proof. If a series of parallel lines, cutting two straight lines, intercept equal distances on one of these lines, they also intercept equal distances on the other.

Problem 11. *To construct a triangle having given the three sides.*

Draw the three sides, AC , $2\frac{3}{4}$ inches long; EF , $1\frac{1}{2}$ inches long; and MN , $2\frac{1}{8}$ inches long.

Draw RS equal in length to AC . With R as a center and a radius equal to EF describe an arc. With S as a center and a radius equal to MN draw an arc cutting the arc previously drawn, at T . Connect T with R and S to form the triangle.

Problem 12. *To construct a triangle having given one side and the two adjacent angles.*

Draw the line MN $3\frac{1}{4}$ inches long and draw two angles AOD and EFG about 30 degrees and 60 degrees respectively.

Draw RS equal in length to MN and with R as a vertex and RS as one side construct an angle equal to AOD . In a similar manner construct at S an angle equal to EFG . Draw lines from R and S through the two established points until they meet at T . The triangle RTS will be the required triangle.

Lettering. Draw the pencil lines and put in the lettering as in plates already drawn.

Inking. In inking *Plate V*, follow the principles previously used and do not make certain lines dotted until sure that they should be dotted.

After inking the figures, ink in the border lines and the lettering as already explained.

PLATE VI

Penciling. Lay out this plate in the same manner as the preceding plates.

Problem 13. *To describe an arc or circumference through three given points not in the same straight line.*

Locate the three points *A*, *B*, and *C* with a distance between *A* and *B* of about 2 inches and a distance between *A* and *C* of about $2\frac{1}{4}$ inches. Connect *A* and *B* and *A* and *C*. Erect perpendiculars to the middle points of *AB* and *AC* as explained in Problem 1. Now draw light pencil lines connecting the intersections *I* and *J* and *E* and *F*. These lines will intersect at *O*.

With *O* as a center and a radius equal to the distance *OA*, describe the circumference passing through *A*, *B*, and *C*.

Proof. The point *O* is equally distant from *A*, *B*, and *C*, since it lies in the perpendiculars to the middle points of *AB* and *AC*. Hence the circumference will pass through *A*, *B*, and *C*.

Problem 14. *To inscribe a circle in a given triangle.*

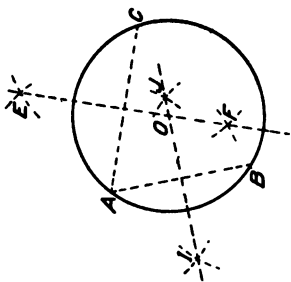
Draw the triangle *LMN* of any convenient size. *MN* may be made $3\frac{1}{2}$ inches, *LM*, $2\frac{3}{4}$ inches, and *LN*, $3\frac{1}{2}$ inches. Bisect the angles *MLN* and *LMN* by the method used in Problem 8. The bisectors *MI* and *LJ* intersect at *O*, which is the center of the inscribed circle. The radius of the circle is equal to the perpendicular distance from *O* to one of the sides.

Proof. The point of intersection of the bisectors of the angles of a triangle is equally distant from the sides.

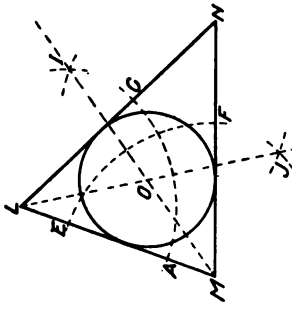
Problem 15. *To inscribe a regular pentagon in a given circle.*

With *O* as a center and a radius of about $1\frac{1}{2}$ inches, describe the given circle. With the T-square and triangles draw the center lines *AC* and *EF* perpendicular to each other and passing through *O*. Bisect one of the radii, *OC*, at *H* and with this point as a center and a radius *HE*, describe the arc *EP*. This arc cuts the diameter *AC* at *P*. With *E* as a center and a radius *EP*, draw arcs cutting

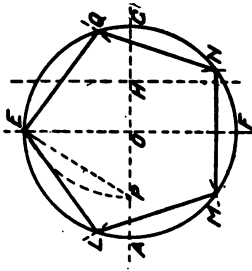
PLATE VI



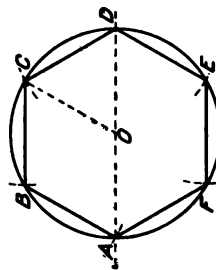
Problem 13



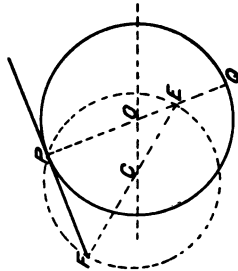
Problem 14



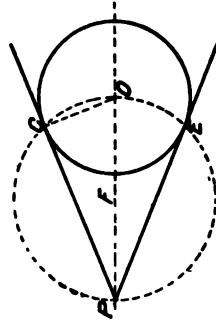
Problem 15



Problem 16



Problem 17



Problem 18

the circumference at L and Q . With the same radius and centers at L and Q , draw the arcs cutting the circumference at M and N .

The pentagon is completed by drawing the chords EL , LM , MN , NQ , and QE .

Problem 16. *To inscribe a regular hexagon in a given circle.*

With O as a center and a radius of $1\frac{3}{8}$ inches draw the given circle. With the T-square draw the diameter AD . With D as a center, and a radius equal to OD , describe arcs cutting the circumference at C and E . Now with C and E as centers and the same radius, draw the arcs, cutting the circumference at B and F . Draw the hexagon by joining the points thus formed.

Therefore, in order to inscribe a regular hexagon in a circle, mark off chords equal in length to the radius.

To inscribe an equilateral triangle in a circle the same method may be used, the triangle being formed by joining the opposite vertices of the hexagon.

Proof. Since the triangle OCD is an equilateral triangle by construction, the angle COD is one-third of two right angles and one-sixth of four right angles. Hence arc CD is one-sixth of the circumference and the chord is a side of a regular hexagon.

Problem 17. *To draw a line tangent to a circle at a given point on the circumference.*

With O as a center and a radius of about $1\frac{1}{4}$ inches draw the given circle. Assume some point P on the circumference and join the point P with the center O . By the method given in Problem 6, *Plate IV*, construct a perpendicular to PO , which perpendicular will be the desired tangent to the circle at the point P .

Proof. A line perpendicular to a radius at its extremity is tangent to the circle.

Problem 18. *To draw a line tangent to a circle from a point outside the circle.*

With O as a center and a radius of about 1 inch draw the given circle. Assume P some point outside of the circle about $2\frac{1}{2}$ inches from the center. Draw a straight line passing through P and O . Bisect PO and with the middle point F as a center describe the circle passing through P and O . Draw a line from P through the intersection of the two circumferences C . The line PC is tangent to the given circle. Similarly PE is tangent to the circle.

Proof. The angle PCO is inscribed in a semicircle and hence is a right angle. Since PCO is a right angle, PC is perpendicular to CO . The perpendicular to a radius at its extremity is tangent to the circumference.

Inking. In inking *Plate VI*, the same method should be followed as in previous plates.

PLATE VII

Penciling. Lay out this plate in the same manner as the preceding plates.

Problems 19 and 20. *To draw an ellipse when the axes are given.*

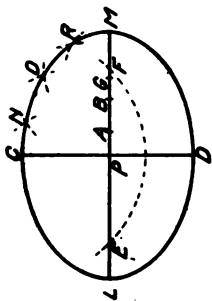
First Method. Draw the lines LM and CD about $3\frac{1}{4}$ and $2\frac{1}{4}$ inches long respectively, making CD perpendicular to LM at its middle point P and having $CP = PD$. The two lines, LM and CD , are the axes. With C as a center and a radius LP equal to one-half the major axis, draw the arc, cutting the major axis at E and F . These two points are the foci.

Now locate several points on PM , such as A , B , and G . With E as a center and a radius equal to LA , draw arcs above and below LM . With F as a center and a radius equal to AM describe short arcs cutting those already drawn as shown at N . With E as a center and a radius equal to LB draw arcs above and below LM as before. With F as a center and a radius equal to BM , draw arcs intersecting those already drawn as shown at O . The point R and others are found by repeating the process. The student is advised to find at least 12 points on the curve—6 above and 6 below LM . These 12 points with L , C , M , and D will enable him to draw the curve.

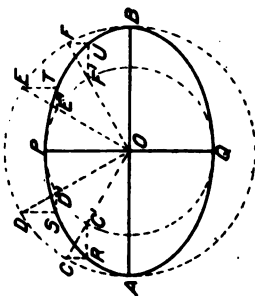
After locating these points, draw a free-hand curve passing through them.

Second Method. Draw the two axes AB and PQ in the same manner as in the first method. With O as a center and a radius equal to one-half the major axis, describe a circle. Similarly with the same center and a radius equal to one-half the minor axis, describe another circle. Draw any radii such as OC , OD , OE , OF , etc., cutting both circumferences. These radii may be drawn with the 60 and 45 degree triangles. From C , D , E , and F , the points of intersection of the radii with the large circle, draw *vertical* lines and from C' , D' , E' , and F' , the points of intersection of the radii with

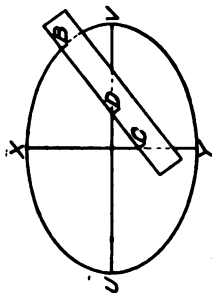
PLATE VII



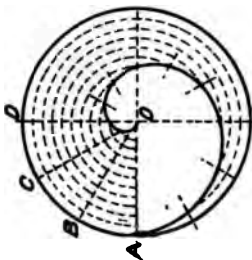
Problem 19



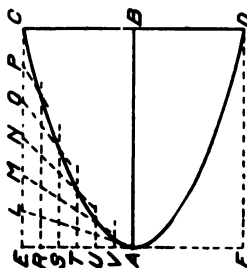
Problem 20



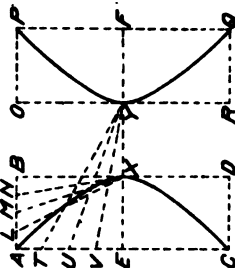
Problem 21



Problem 22



Problem 23



Problem 24

the small circle, draw *horizontal* lines. The intersections of these lines are points on the ellipse.

Draw a free-hand curve* passing through these points; about five points in each quadrant will be sufficient.

Problem 21. *To draw an ellipse by means of a trammel.*

As in Problems 19 and 20, draw the major and minor axes, UV and XY . Take a slip of paper having a straight edge and mark off CB equal to one-half the major axis, and DB equal to one-half the minor axis. Place the slip of paper in various positions keeping the point D on the major axis and the point C on the minor axis. If this is done, the point B will mark various points on the curve. Find as many points as necessary and sketch the ellipse.

Problem 22. *To draw a spiral of one turn in a circle.*

Draw a circle with the center at O and a radius of $1\frac{1}{2}$ inches. Locate twelve points, $\frac{1}{8}$ inch apart on the radius OA and draw circles through these points. With the 30-degree triangle, draw radii OB, OC, OD , etc., 30 degrees apart, thus forming 12 equal parts.

The points on the spiral are now located; the first is at the center O ; the next is at the intersection of the line OB and the first circle; the third is at the intersection of OC and the second circle; the other points are located in the same way. Sketch in pencil a smooth curve passing through these points.

Problem 23. *To draw a parabola when the abscissa and ordinate are given.*

Draw the straight line AB —about three inches long—as the axis, or *abscissa* of the parabola. At A and B draw the lines EF and CD perpendicular to AB , and with the T-square draw EC and FD , $1\frac{1}{2}$ inches above and below AB , respectively. Let A be the vertex of the parabola. Divide AE and EC into the same number of equal parts. Through R, S, T, U , and V , draw horizontal lines and connect L, M, N, O , and P , with A . The intersections of the horizontal lines with the oblique lines are points on the curve. For instance, the intersection of AL and the line V is one point and the intersection of AM and the line U is another.

The lower part of the curve AD is drawn in a similar manner.

Problem 24. *To draw a hyperbola when the abscissa EX , the ordinate AE , and the diameter XY are given.*

*See Page 16, Mechanical Drawing, Part I.

Draw EF about 3 inches long and mark the point X , 1 inch from E and the point Y , 1 inch from X . With the triangle and T-square, draw the rectangles $ABDC$ and $OPQR$ such that AB is 1 inch in length and AC , 3 inches in length. Divide AE and AB into the same number of equal parts. Connect Y with the points T , U , and V , on AE , and connect X with L , M , and N , on AB . The first point on the curve is at A ; the next is at the intersection of TY and LX ; the third is at the intersection of UY and MX . The remaining points are found in the same manner. Repeat the process for XC and the right-hand curve PYQ .

Inking. In inking the figures on this plate, use the French or irregular curve and make full lines for the curves and their axes. Dot the construction lines as usual. Ink in all the construction lines used in finding one-half of a curve, and in Problems 19, 20, 23, and 24 leave all construction lines in *pencil* except those inked. In Problems 21 and 22 erase all construction lines not inked. The trammel used in Problem 21 may be drawn in the position shown, or outside of the ellipse in any convenient place.

The same lettering should be done on this plate as on previous plates

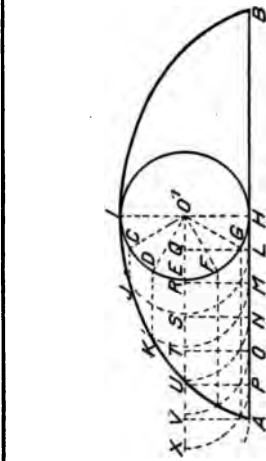
PLATE VIII

Penciling. In laying out *Plate VIII*, draw the border lines and horizontal and vertical center lines as in previous plates, dividing the plate into four spaces.

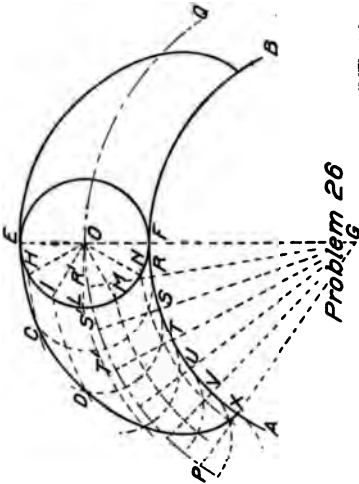
Problem 25. *To construct a cycloid when the diameter of the generating circle is given.*

With O' as a center and a radius of $\frac{7}{8}$ inch draw a circle, and, tangent to it, draw the indefinite horizontal straight line AB . Divide the circle into any number of equal parts—12 for instance—and through these points of division C , D , E , F , etc., draw horizontal lines. Now with the dividers set so that the distance between the points is equal to the chord of the arc CD , mark off the points L , M , N , O , P , on the line AB , commencing at the point H . At these points erect perpendiculars to the center line XO' which is the line of centers of the generating circle as it rolls along the line AB . With the intersections Q , R , S , T , etc., as centers describe arcs of circles as shown. The points on the cycloid will be the intersections of

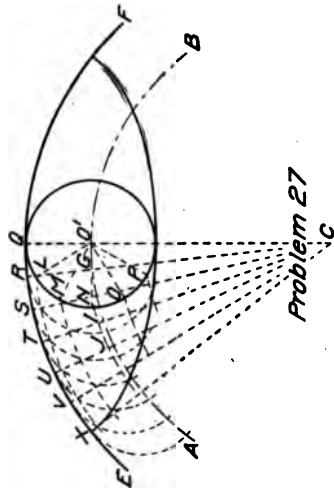
PLATE VIII



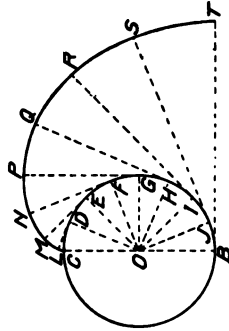
Problem 25



Problem 26



Problem 27



Problem 28

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